

# HISTORICAL CHANGES ON SANDY SHORELINES IN VICTORIA

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**ABSTRACT:** Comparison of features mapped in the mid-19th century with those recorded on air photographs taken in 1935-45 and with the present configuration indicates the extent of recent changes on sandy shorelines in Victoria. In general sandy shorelines have receded, even on sectors where they had previously prograded (advanced seaward). During the past century, sandy shoreline progradation has been confined to a few scattered sectors where sand deposits are still arriving on the coast. These changes are likely to continue, and their possible effects should be considered by those concerned with the development and conservation of the Victorian coastline.

## INTRODUCTION

The changes that take place on coastlines as the result of erosional and depositional processes have long been of interest to geomorphologists, geologists and engineers. These changes can be studied over various time scales, ranging from a single tidal cycle or a weather episode lasting a few hours to such periods as the fortnightly spring tide cycle, or seasonal variations over a year; to variations over several years, or decades, or over the past century, or several centuries; and to changes that have taken place during the five or six thousand years since the Holocene marine transgression brought the sea up to approximately its present position.

In 1972 the International Geographical Union set up a Working Group to examine coastal changes around the world during the past century, using historical maps, charts and air photographs to trace changes in coastal configuration. By 1976, when the Group issued a preliminary report, it was clear that erosion had been widespread during this period, not only on cliffed coasts, but also on most of the world's sandy shorelines, including barrier sectors with a previous history of progradation (seaward advance) by means of Holocene sand accretion. The extent of the world shoreline that has prograded during the past century has been relatively limited (Bird 1976a). This world-wide study was based on the preparation of reports on national and provincial coastlines, including one from Victoria (Bird 1973a), which is here updated and extended as a record of the geomorphological changes

that have taken place on sandy shorelines on this part of the Australian coast.

## HISTORICAL EVIDENCE

In the mid-nineteenth century the Victorian coast was mapped on a series of Coastal Survey Plans, generally on a scale of two inches to the mile (Fig. 1), preserved in the archives of the Department of Crown Lands. In comparing these with the modern configuration, as shown on recent air photographs or portrayed on maps derived from these photographs and published on scales of 1:250,000 (National Mapping), 1:100,000, and in some areas 1:50,000 (Lands Department), possibilities of errors in surveying and cartography should be borne in mind (Carr 1962). It is not always clear whether the shoreline mapped was that of high or low tide or some intermediate level, or whether the coastline portrayed was the margin of vegetated terrain, such as grassy dunes at the back of a beach, or salt marsh or mangrove scrub behind muddy tidal flats. Where the coast consists of vertical cliffs the alignment is well defined, but where there is a bluff or an irregular coastal slope it is necessary to know whether the lines on the map represented the crest, the foot, or some intermediate feature. In view of these difficulties it is not usually possible to make precise measurements of coastal changes with reference to nineteenth century maps and charts, although much useful information can be gleaned, and some obvious changes detected. This has been illustrated with reference to Smythe's maps of the shoreline of Westernport Bay in 1849 (Bird

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& Barson 1975), and further examples will be given below.

The Victorian coastline was covered by air photographs taken by the Royal Australian Air Force between 1936 and 1945, the negatives being on scales ranging from 1:14,550 to 1:20,000. Earlier photography is available for parts of Port Phillip Bay, and some sectors have been photographed several times since the late nineteen-forties. Complete coverage is available from high-level photographs taken in 1965-7 (scale: 1:84,480) as a basis for the preparation of the National Mapping 1:250,000 series. Careful comparison of shorelines on photographs taken at different dates has been used to detect, and in some cases to measure, shoreline changes over the intervening periods.

Some possible sources of error must be acknowledged. Air photographs (especially the older ones) are subject to radial and tilt distortion, and the imagery may be further distorted by stretching or shrinkage of negatives or prints. The portrayal of the shoreline varies according to state of tide (on the Victorian ocean coast the inter-tidal zone is often 100 to 200 metres wide, and in embayments such as Westernport and Corner Inlet, much wider) and the state of the sea; it is sometimes difficult to trace a shoreline adjacent to shallow water areas where sea floor features are visible. Such features as bars (which may emerge at low tide), migratory berms, beach cusps, and beach lobes, complicate the recognition and delineation of a sandy shoreline. Changes in the extent of salt marsh and mangrove vegetation are usually obvious, but the extent of vertical change by erosion or sedimentation, relevant to the question of coastal advance or retreat, is usually too small to be demonstrable from air photographs, and transverse profiling by photogrammetric methods is impeded because the terrain surface is concealed by vegetation. On the other hand, changes on steep and cliffed coasts, often dramatic, are readily seen, and often measurable (Gill 1973, 1977).

The most effective method has been to enlarge or reduce the air photographs to a common scale (usually 1:10,000) for comparative study. On this scale it is not possible to measure changes of less than 0.2 millimetres, so that measurements are only accurate within  $\pm 1$  metre on the ground. Changes of this order can be detected on well-defined linear features such as vertical cliffs, eroding dune margins, or a truncated salt marsh, but changes on more gradual slopes or on open sandy beaches can rarely be determined within  $\pm 5$  metres. For more accurate data it is necessary to institute monitoring by repeated ground surveys along transverse shore profiles at selected locations. This has been done locally, on a limited scale, and for short periods, notably by the Ports and Harbors Division of

the Public Works Department in their investigations of eroding sectors where coast defence measures may be required.

In the absence of a comprehensive and sustained programme of monitoring past shoreline changes it is necessary to retrieve as much information as possible from cartographic evidence and air photography. On some sectors, dated ground or air oblique photographs, and even sketches or paintings, offer supplementary information on the configuration of the coast in the past. This kind of material has been sought from archives, but much of it is widely scattered and privately owned, and discovered only by chance. Possibly this attempt to put on record some evidence of recent changes along sandy sectors of the Victorian coast will bring to light further material relevant to the question of the nature and extent of such changes.

## THE VICTORIAN COASTLINE

The coastline of Victoria (including Port Phillip and Westernport Bays) is about 1700 km long, when measured by means of one-kilometre intercepts on 1:250,000 maps. Of this, about 700 km are sandy shoreline, backed by sandy terrain such as beach ridges or coastal dunes. The remainder is partly steep and rocky, in the form of cliffs and bluffs, some of which are bordered by narrow beaches of sand or gravel, and partly low-lying alluvial and swamp terrain, with a seaward fringe of salt marshes, and in some places mangroves. Further details are available in a geological and geomorphological account of the coast of Victoria published by the Town and Country Planning Board (Bird 1977). Evidence for recent changes on this coastline will be treated in sequence from Discovery Bay in the west to Cape Howe in the east.

## DISCOVERY BAY

The long, gently curving sandy shore of Discovery Bay is backed by extensive dune topography, including large active dunes. The seaward margin is generally cliffed, partly in dune calcarenite (as at Cape Montesquieu), and partly in unconsolidated, grassy foredunes. Although at times constructive wave action builds up the beach, and wind action develops a newer foredune or grassy terrace,\* these features are not maintained, and comparison with historical maps and air photographs indicates that the sandy shoreline has retreated. Near the western end, the beach is interrupted by the mouth of the Glenelg River, the features of which were surveyed by Thomas Mitchell in 1836.

\*Foredune ridges are built upwards by sand accretion in tussocky grasses (*Festuca littoralis* or *Ammophila arenaria*), whereas terraces are built outwards by sand accretion in spreading grasses (*Spinifex hirsutus*).

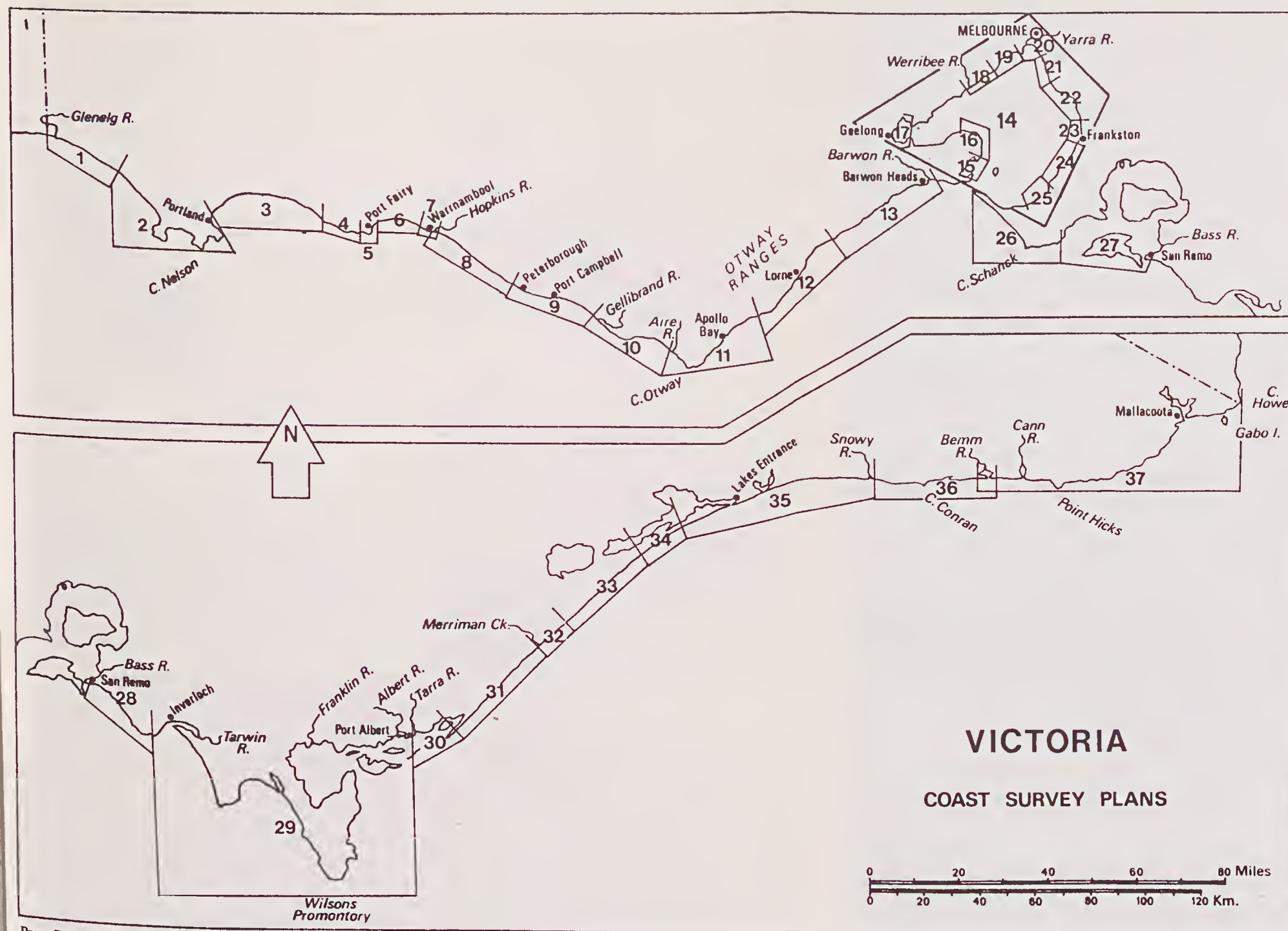


Fig. 1—

1. Clarke 1850
2. Clarke 1850
3. Wade 1851
4. Townsend 1840
5. Barrow 1850
6. Barrow 1854
7. Barrow 1853
8. Smythe 1847
9. Smythe 1847
10. Smythe 1847
11. Smythe 1869
12. Smythe 1846
13. Smythe 1847
14. Hobson 1836
15. Ross 1860
16. Cox 1861
17. Ross 1859
18. Cox 1861
19. Cox 1861
20. Ross 1858
21. Cox 1861
22. Cox 1862
23. Cox 1862
24. Cox 1862
25. Cox 1862
26. Smythe 1841
27. Smythe 1842
28. Smythe 1843
29. Smythe 1847-48
30. Smythe 1847
31. Smythe 1847
32. Smythe 1847
33. Smythe 1848
34. Smythe 1848
35. Smythe 1849
36. Smythe 1849-52
37. Smythe 1849-52





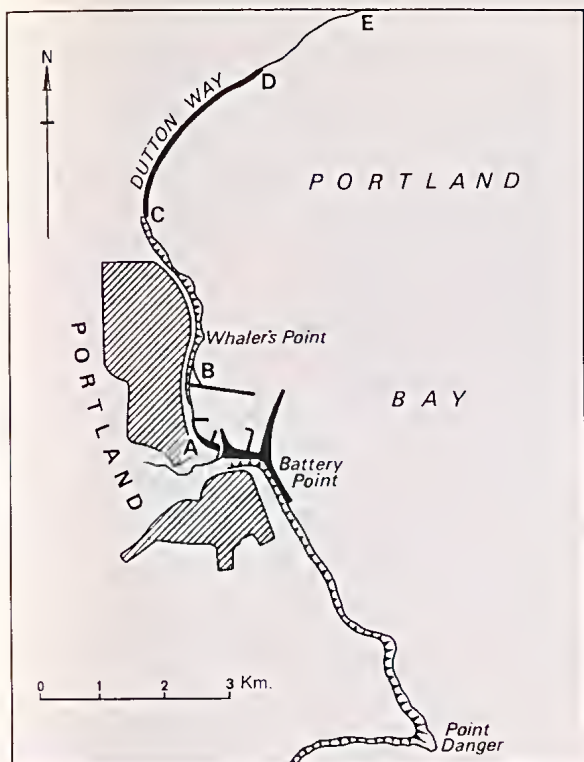


Fig. 2—Coastal features near Portland, Victoria.

Comparison of Mitchell's map with an air photograph taken in 1967 shows little change, except that there is now a more winding outlet from the river through a more extensive sandy threshold at the mouth, and the dunes immediately to the east have been cut back, and only partly rebuilt (J. F. Bird 1977).

#### BRIDGEWATER BAY AND THE PORTLAND COAST

Bridgewater Bay, between steep promontories of hard volcanic rock west of Cape Nelson, also has coastal dunes with a seaward margin trimmed back by marine erosion, and the same is true in Portland Bay, except for a small sector near the town of Portland, where the sandy shoreline has advanced within the harbour area (A, Fig 2). Comparison of Tyers' plan of Portland Bay, surveyed in 1840, with later maps and air photographs shows that the beach prograded after piers were built in 1846 and 1857-8, and particularly after the construction of a breakwater in 1891. Later these structures were removed or modified, and the present large stone breakwaters added in 1957-61 to enclose Portland Harbour. The prograded beach has been partly built over, but further accretion has taken place on the northern side of the lee breakwater (B, Fig 2), and it appears that breakwater construction has modified the pattern of waves in such a way as to create a sheltered environment into which beach sand has drifted.

There has been rapid beach erosions at Dutton Way, to the north, during the fifteen years since the large breakwaters were built at Portland, and it is possible that these breakwaters now refract the waves in such a way as to intensify wave energy reaching this shore. Boulders have been dumped to reduce erosion (CD, Fig 2), but as on other parts of the coast this has been followed by a narrowing and lowering of the beach in front of the boulders, while erosion has continued (and perhaps intensified) beyond their eastern limits (DE, Fig 2), where the eroding sandy shoreline is backed by multiple dune ridges indicative of earlier progradation. Dutton Way is thus a sector where erosion has accelerated as a sequel to engineering works, but sandy shoreline erosion is so widespread that there would probably have been some erosion here even without such structural modifications.

#### PORT FAIRY

Local progradation has taken place alongside breakwaters built in the eighteen-seventies to secure a navigable entrance to the river-mouth harbour at Port Fairy. Barrow's plan, surveyed in 1854, and Stanley's chart of 1870 show several rocky islands off the mouth of the Moyne River, with extensive intertidal and submerged sand shoals. Later maps and air photographs show that since the breakwaters were built and extended, sand has accreted above high tide level to advance the shoreline on their southern side, along the broad beach linking Griffith Island to Rabbit Island. On the northern side the beach has been cut back, and shore protection works have been introduced, with similar effects to those at Dutton Way, but there has been little change in the sandy shoreline behind the basalt reefs at Killarney.

#### WARRNAMBOOL

Cliffs in Pleistocene dune calcarenite south and west of Warrnambool have been subject to erosion during storms, but Lady Bay has been a sector of beach progradation. Early maps show that the Merri River opened to the sea alongside a sand spit at the western end of Lady Bay, in the lee of a chain of rocky islands and reefs. Attempts were made to improve the shelter of this part of Lady Bay as a boat anchorage, notably by the building of a viaduct to link one of the offshore islands to the mainland, and a stone breakwater extending out from this island into Lady Bay. As these structures were built (1884-90) the sandy shoreline to the north began to prograde, and in 1925 the Royal Commission on Victorian Outer Ports estimated that during the preceding forty years some 1.2 million cubic yards of sand had been deposited, advancing the beach within the harbour by about 150 yards. The viaduct

was then filled in to form a causeway, with the aim of preventing inflow of sand from the mouth of the Merri River (then assumed to be the major source of the sand), and the breakwater was extended out into deeper water. However, progradation has continued with sand being washed up from the floor of Lady Bay, and harbour remains very shallow (Duberry 1978).

#### APOLLO BAY

Apollo Bay is another sector where local beach progradation has occurred within a harbour as a sequel to breakwater construction. Again the harbour lies on the lee side of a headland, and is sheltered from ocean swell and waves generated by the prevailing south-westerly winds. Engineers have sought to improve the natural anchorage by building protective breakwaters, and in so doing have created an environment where sand deposition has ensued in one area when beach erosion has prevailed elsewhere. Comparison of air photographs taken in 1946 and 1974 shows that deposition has occurred mainly to the north of the harbour, where grassy dunes have formed behind a sandy beach that has built up within the past thirty years (Plates 3 & 4 in Bird 1973a).

#### PORT PHILLIP BAY

Recession has taken place along cliffs and intervening beach sectors on the ocean coast between Cape Otway and Wilsons Promontory, but patterns of change have been more complex within Port Phillip Bay and Westernport Bays. At the entrance to Port Phillip Bay, Point Lonsdale Bight receives an intermittent supply of sand drifting in from the ocean shore, particularly during winter storms, when sand drifting from the west moves round the point and northwards past Point Lonsdale (McArthur 1977). The sector north to Queenscliff and Swan Island has been built up in Holocene times by the deposition of sand swept into the entrance to Port Phillip Bay and carried northward by a combination of south-easterly waves and current action (Fig 3). Swan Island is essentially a recurved spit, which has shown complex changes in configuration. Riedel and Fidge (1977) examined fifteen surveys carried out between 1886 and 1976, and found evidence of the migration of successive lobate forelands along the eastern flank of Swan Island, one reaching the northern end between 1910 and 1923, the next between 1949 and 1968.

Nautical charts of 1837 and 1859-60, and the military map of 1928, show a variable barrier and spit

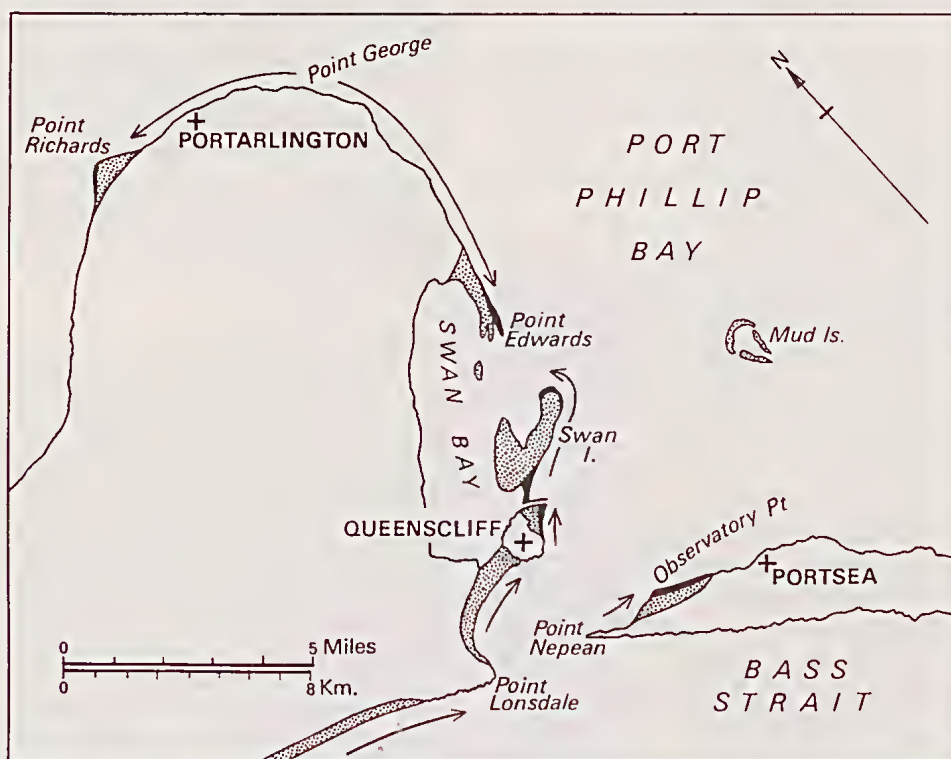


Fig. 3—Coastal features and longshore drifting at the entrance to Port Phillip Bay. Sandy areas are stippled, except for sectors of historical progradation, shown in black.



topography in the area between Queenscliff and Swan Island, and fluctuations of the tidal channel here may have been responsible for the irregularities in sand supply to Swan Island, producing the migrating lobate forelands. A breakwater was built at Queenscliff in 1935 and extended in 1955-6 to protect the entrance to a boat harbour. After the breakwater was extended there was rapid sand accretion on its southern side between 1957 and 1961, when about 1.25 million cubic metres accumulated in the form of a triangular foreland (Riedel & Fidge 1977). North of the breakwater the barrier and spit topography has been reshaped, and with the sand supply interrupted, erosion has become prevalent on the eastern shore of Swan Island (Plate 1). By 1961, accretion had prograded the shoreline south of the breakwater to such an extent that sand was moving into the approach to the boat harbour. Repeated dredging is necessary to maintain the channel by removing about 70,000 cubic metres of sand per year and dumping it in the shoal area to the north.

Changes have also occurred on the shores of Lonsdale Bight, which are backed by dunes built up during an earlier phase of deposition, but are now cliffed and eroding. The drift of sand along and across Lonsdale Bight has been insufficient to maintain the

shoreline here. Erosion of the shoreline became severe at Point Lonsdale in the early years of the present century, after the navigable entrance channel to Port Phillip Bay had been enlarged by blasting away part of the rocky sea floor (Dunn 1970.) It is unlikely that this change in sea floor configuration had much effect on wave and current patterns; it is more likely that here, as elsewhere on the Victorian coast, beach erosion had already begun, and that it was noticed only after the township of Point Lonsdale had been sited there. The response to this erosion has been the building of sea walls and groynes in a sequence that has gradually spread along the shores of the Bight, with continuing, and perhaps accentuated, erosion cutting out asymmetrical coves beyond each extension in turn (Fig 4). Despite criticisms of this kind of sea wall construction, it seems inevitable that the whole of Lonsdale Bight will eventually be walled, and that local people will either have to be content with the lower and narrower sandy beaches that survive in front of walls of this kind, or ask for the beach to be restored artificially (McArthur 1977).

Edwards Point, north of Swan Island, is a similar spit that has grown southwards, the two structures comprising a paired spit formation that constricts the



PLATE 1

The eastern shore of Swan Island, Port Phillip Bay, showing a migrating sand lobe. (*N. Rosengren, August 1973*)

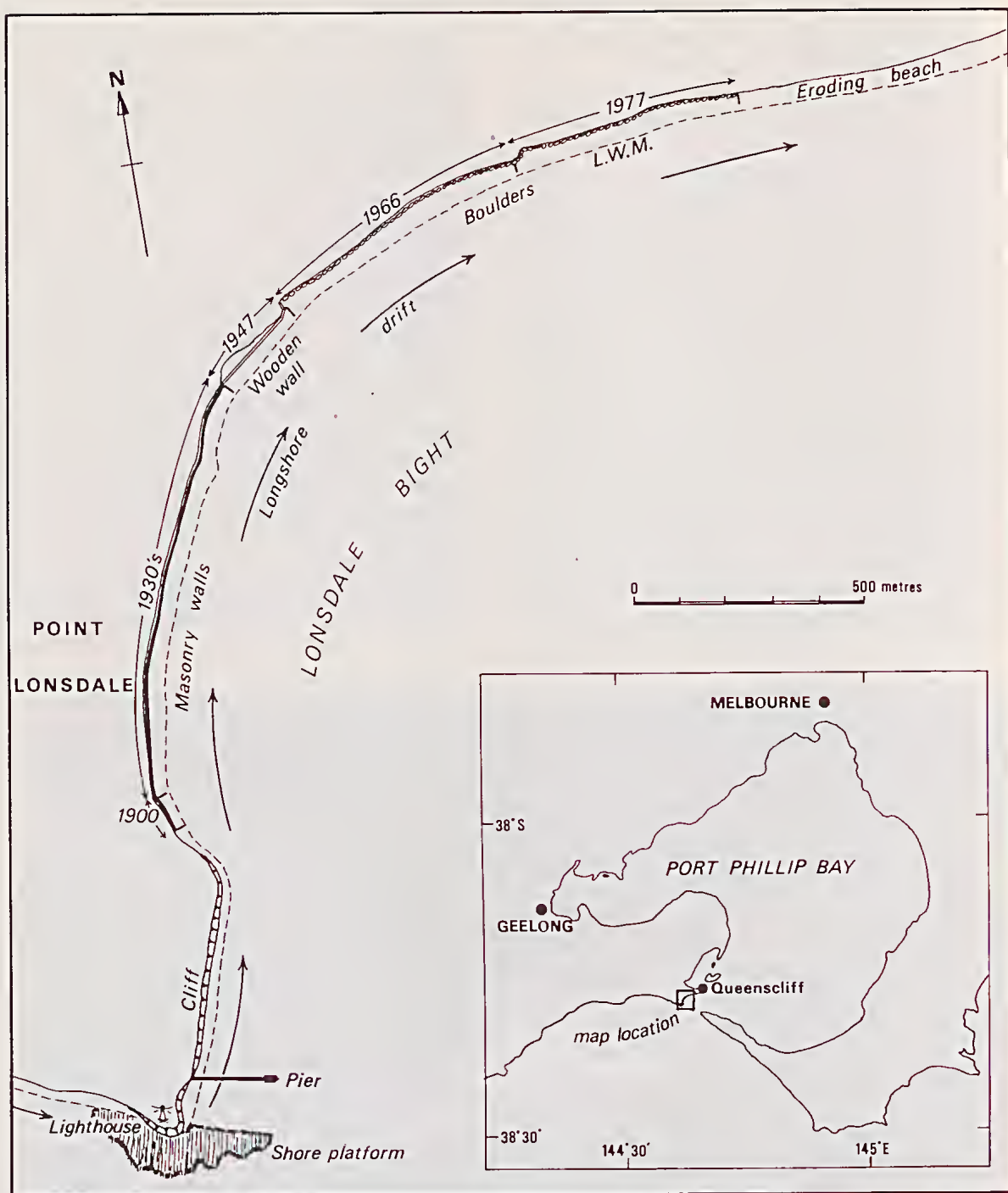


Fig. 4—Sequence of sea wall construction in Lonsdale Bight.

entrance to Swan Bay (Fig 3). The present outer sand ridge, not shown on 19th century maps and charts, has been added since Mason's survey of 1896. The spit incorporates quartzose sand and some ferruginous gravel which has drifted southwards from the eroding cliffed coast at St. Leonards, together with shelly gravel derived from the fauna of adjacent shallow

waters (Barson 1973). At St. Leonards there has been local cusped deposition within a small harbour, and minor accretion on the sandy foreland to the north.

Point Richards, west of Portarlington, is a cusped foreland that has gained new ridges on its western shoreline in recent decades (Fig 3). It is similar to Edwards Point in composition, and is supplied by



westward drifting of sand and gravel. A 'drift parting' thus exists near Point George, as the result of the arrival of waves generated by winds from the quadrant between NNE and ESE, where the fetch across Port Phillip Bay attains 40 km. On the western shore of Port Phillip Bay the shelly spits and islets at the Sand Hummocks have shown intricate, small scale changes in outline on air photographs taken in 1947, 1970, and 1974, the overall trend being one of shoreline recession. At Altona and Williamstown, changes have been due largely to reclamation works and sea wall construction, and in recent years beaches have been artificially replenished.

There are several minor sectors of sustained sand accretion related to the building of breakwaters to shelter boat harbours on the eastern shores of Port Phillip Bay, notably at St. Kilda and Brighton, where cusped forelands have developed in the lee of breakwaters; Sandringham, where the harbour breakwater has intercepted beach material that formerly moved to and fro in a seasonal drift alternation (Bird 1972); Mordialloc, where sand accretion has occurred on the northern side of a breakwater; and Rye, where progradation has been augmented by the dumping onshore of sand dredged from offshore sources. Cluffed sectors of this shoreline have generally receded, although sea wall construction has halted this, especially since the nineteen-thirties. Many of the former cliffs have been replaced by landscaped bluffs, as at Brighton, Black Rock, and Mentone, a procedure that has cut off the former supply of sand from the cliffs and resulted in beach depletion (Bird 1972). Natural erosion, hastened by the impact of people scrambling on the cliffs, is still to be seen at Red Bluff and Black Rock Point (Bird, Cullen & Rosengren 1973). In recent years the P.W.D. Ports and Harbours Division has initiated artificial beach nourishment schemes, using sand dredged from the sea floor, to replace eroded beaches at Mentone and Aspendale, and this method is likely to be used elsewhere to restore or improve beaches in demand for recreational use.

Observatory Point, south of Portsea, is a sandy foreland that developed in stages marked by beach ridges on a sector where ocean swell, refracted through Port Phillip Heads, has combined with locally-generated waves and currents to supply and shape an area of sand deposition (Fig 3). The western shore is now cluffed and receding, a change that could be attributed to intensified wave energy following the enlargement of the entrance to Port Phillip Bay, but is probably part of the more widespread onset of sandy shoreline erosion here documented. Some of the sand eroded from this shore has drifted round to the north-facing shore, which has continued to advance, and thus shows the features typical of a prograding sandy

shoreline. The transverse profile of the beach is convex-upward, backed by a newly-developed beach ridge which is being colonised by dune grasses; the resulting foredune remains uncluffed, and uninterrupted by blowouts.

Mud Islands, a group of low sandy and marshy islets on a shoal in the southern part of Port Phillip Bay, have varied in configuration since they were first mapped in 1836. The changes have been traced from maps and charts compiled in 1859-60, 1864, 1932 and 1946, and from air photographs taken in 1951 and 1969 (Bird 1973b). In the course of these changes a new ridge of shelly sand was added to form Boatswains Beach on the southwestern shoreline, but this progradation was only temporary, for in 1962 a storm surge drove the beach back on to the salt marsh to the rear, so that the present shoreline is in much the same position as that of 1836.

#### WESTERNPORT BAY

Recent changes on shorelines bordering Westernport Bay were described and discussed by Bird and Barson (1975). There has been further erosion on sandy sectors, notably at Somers and Cowes, and accretion on spits supplied with sand by longshore drifting: accretion during the past four years has widened Sandy Point, added a new recurve to Stockyard Point, and lengthened Observation Point on Phillip Island. There have also been gains and losses in the extent of salt marsh and mangroves on the shores of Westernport Bay, with continuing revival of mangroves in some sectors from which they had previously disappeared, notably to the south of Stony Point.

At the eastern entrance to Westernport Bay, sand is being supplied to the shores of Cleeland Bight by an active dune spilling from the isthmus north of Cape Woolamai. A combination of south-easterly wave action and inflowing tidal currents has carried this sand around the shores of the Bight, which have prograded by up to 300 m since this area was surveyed by Smythe in 1842 (Plate 2). Recently-built foredunes back sectors of this shoreline north to the road bridge, and there has been similar accretion on Davis Point, south of San Remo, where foredune growth proceeded in the interval between 1939 and 1973 air photography. The sand supply here is derived from shoals to the south, which are probably fed, in turn, by tidal redistribution of sand arriving in Cleeland Bight.

#### SOUTH GIPPSLAND

Cliffs and beaches on the ocean coast between San Remo and the western shores of Wilsons Promontory have generally receded, but in two sectors there has been an advance of the sandy shoreline in recent



PLATE 2

The prograded sandy shoreline in Cleeland Bight, on the east coast of Phillip Island, fed with sand from the active Woolamai dunes in the background. (*E. C. F. Bird, February 1977*)





PLATE 3

Sand shoals moving into the entrance to Andersons Inlet at Inverloch. A spit is building up off Point Smythe, to the left, and lobes of sand are migrating along the Inverloch shore, to the right. (*K. G. Boston, March 1976*)

years. South of Inverloch new grassy beach ridges have added to the western shore of Venus Bay, and an extensive sandy flat has built up off Point Smythe, narrowing the tidal channel at the mouth of Andersons Inlet (Plate 3). A lobe of sand has moved in along the Inverloch shore since 1950 (Boston 1971) in much the

same way as have the sand lobes on Swan Island. Prograded sandy terrain has also developed on sectors of the shoreline of Waratah Bay on either side of the migratory mouth of Shallow Inlet (Smith 1969). Within Andersons Inlet, Boston has documented early stages in the development of new marshland and the

associated re-shaping of intertidal topography following the introduction of *Spartina anglica* in 1962, a remarkable example of a vegetation-induced coastal change (Boston 1973).

#### WILSONS PROMONTORY AND CORNER INLET

Changes have been very slow on the hard granites of Wilsons Promontory: indeed, the period since the Holocene marine transgression brought the sea to its present level has seen little change here beyond the removal of the weathered mantle and the development of minor weathering features on the bedrock surfaces thus exposed. The southern shores of Corner Inlet have been receiving sand from active dunes spilling from Yanakie isthmus in much the same way as those of Cleeland Bight, but this area is sheltered from strong wave action and the sand has been dispersed, largely by tidal currents, to form intertidal shoals instead of prograding the beach. Salt marsh and mangrove-

fringed areas on the northern and western shores of Corner Inlet have shown changes similar to those described by Bird and Barson (1975) at Westernport Bay, but these have not yet been investigated in detail.

Sandy shorelines in each of the coves bordering Wilsons Promontory have receded during recent decades to produce cliffed dune margins, but on the northeastern corner there is an extensive beach ridge system, and a part of the coastline here has advanced as a new sandy foreland, while adjacent shores to the north and south have been cut back. A comparable bulging of the shoreline occurred at earlier stages, commemorated in the pattern of beach ridges farther inland (Plate 4). Such irregularities in growth probably result from changing patterns of refracted waves over the variable shoals off the adjacent entrance to Corner Inlet.

Similar changes have occurred on the shorelines of barrier islands east of Corner Inlet. The



PLATE 4

Air photograph of northeast Wilsons Promontory. (Crown copyright reserved: Department of Minerals and Energy, Canberra, February 1965)



southern shores of Snake Island have been cut back, but at the Port Albert entrance there has been extensive sandy shoreline progradation. Comparison of air photographs taken in 1941 and 1967 shows the addition of a large sandy area, built up above mid-tide level on the western side of the entrance (Plates 13 & 14 in Bird 1973a). The sandy shoreline east of the entrance has retreated, but there has been substantial accretion at the entrance to Shoal Inlet, 16 km to the east, where a spit grew southwestwards by more than a kilometre in the interval between 1941 and 1967.

#### THE NINETY MILE BEACH

The long sandy shoreline of the East Gippsland coast typically shows a cliffed dune margin to the rear of the present beach (Plate 5), and comparisons of the Coastal Survey Plans (1846-49) with air photographs taken in 1967 indicate that a recession of up to 150 metres has taken place. The Ninety Mile Beach is the seaward margin of an outer barrier that had previously prograded to form a succession of dune ridges. Such dunes develop as the result of alternations of shoreline advance and retreat (sequences of 'cut-and-fill' as described by Davies in 1957), and one interpretation of the present situation could be that a retreat phase has lately prevailed, and will duly give place to another advance phase, when a new and persistent sand ridge will be added to prograde the shoreline. However, the present retreat phase has been on a much larger scale

than any earlier phase of shoreline recession, for the previously-built dune ridges show no evidence of earlier episodes of disruptions by blowouts comparable with those that have now developed from the seaward margin. There have been recurrent phases of new foredune initiation in front of sectors of cliffed dune margin, but these are impersistent, and do not survive episodes of storm wave activity. For some reason the intermittent shoreline progradation that prevailed earlier in Holocene times has given place to a dominance of erosion.

The dune ridges were built roughly parallel to the Ninety Mile Beach, but vary in number from one at Seaspray, Bunga Arm and Lakes Entrance to thirteen at Letts Beach. Where there is only one, it has generally been a transgressive ridge, moving landward as the beach was cut back, and now held in place by marram grass plantings; where there are several, the lateral variation is due partly to divergence, and partly to truncation of sinuous ridges along the present backshore (Huzzey 1975). In the McLaughlins Beach sector up to six ridges have been pared away along a straightened shoreline that truncates an earlier lobate foreland.

As the beach was cut back, blowouts formed, and in many places sand is spilling across the previously vegetated dune ridges behind the Ninety Mile Beach. At McLaughlins Beach a meandering tidal channel behind the outer barrier broke through in a



PLATE 5

A receding sandy shoreline: the Ninety Mile Beach near Ocean Grange. (*E. C. F. Bird, November 1965*)

storm in 1961 to form a new outlet that has since widened. At Seaspray, there have been changes at the mouth of Merrimans Creek since it was mapped in 1847 by Smythe. These are due partly to shoreline retreat and the landward movement of dunes (McKay 1978).

The only part of the Ninety Mile Beach that has advanced is a 2.5 km sector extending either side of the stone jetties that protrude from the artificial entrance to the Gippsland Lakes (Bird & Lennon 1973). Sandy forelands have prograded here, linked by a submerged, looped sand bar off the entrance; their growth is indicated by successively-built foredunes, particularly on the southwestern side. The sand has been supplied by longshore drifting, its interception being related to the breakwaters, and to the effects of constructive wave action on either side of the zone where transverse currents flow in and out of the Gippsland Lakes (Bird 1965, 1978). The pattern of accretion is unusual. As a rule, such breakwaters intercept longshore drift to prograde the up-drift shoreline and result in erosion down-drift, but here there has been accretion on both sides, with longshore drifting from the northeast as well as from the southwest. According to Fryer (1973) the volume of sand accretion in the prograded forelands and looped bar structure is about 13 million cubic metres. Undoubtedly, much of this local accretion has been due to accumulation of sand eroded from the Ninety Mile Beach, which has also been losing sand landward, through blowouts to spilling dunes behind the shore, and seawards to the intermittent sand bars observed in the surf zone.

#### LAKES ENTRANCE TO CAPE HOWE

East of Lakes Entrance, little change can be detected on the sandstone headland at Red Bluff, or on the granitic promontories and cliffs of Lower Palaeozoic rock farther east, but shoreline recession has prevailed on the long sandy beaches that line much of this coast. Minor sectors of at least temporary progradation have been noted at Point Ricardo and Wingan Inlet (Plate 8, Rosengren 1978), and at Pearl Point (Williams 1973) and Clinton Rocks (Harford 1973). At Mallacoota, comparisons of air photographs taken in 1941 and 1966 show removal of a sand ridge on the eastern shore and accumulation of sand on the threshold area that extends into the mouth of the Inlet (Plates 15 & 16 in Bird 1973a). The entrance to Mallacoota Inlet has become very shallow, and occasionally it has been sealed off completely (Williams 1977). Farther east, the cusped feature on the coast behind Gabo Island is the remains of a tombolo that existed here in the 19th century (Rosengren 1978); it changed little in outline between 1941 and 1966, apart from

some paring away of the eastern shoreline, but there have been variations in the topography of largely unvegetated and mobile dunes that extend eastwards through the coastal fringe towards Cape Howe.

#### DISCUSSION

There has been a prevalence of erosion on sandy sectors of the Victorian coastline during the past century. Beach progradation has been confined to a few limited and localised sectors still receiving a sand supply from nearby cliff erosion, from offshore shoals, or from dunes spilling on to leeward shorelines; to the growing spits and cusped forelands nourished by a sand supply derived from nearby erosion; and where longshore drift has been intercepted by breakwaters built to protect harbour entrances. Elsewhere, the beach systems have been losing sand, partly onshore to dune systems, partly alongshore and into the mouths of estuaries and lagoons, and partly offshore to the sea floor. This is a world-wide problem, and several hypotheses have been put forward to explain it, each of which will now be considered in a Victorian context.

On many coastlines, beaches are supplied and maintained by sediment delivered to the coast by rivers and transported by longshore drifting. Where this is the case, as in Southern California, the onset of beach erosion has been correlated with the reduction of fluvial sediment yield following dam construction and reservoir impoundment (Emery 1960). However, this is of little relevance in Victoria, where most of the rivers flow into estuaries or coastal lagoons, which receive the bulk of the sediment discharged. An exception is the Snowy, which carries sand and gravel into the sea at Marlo during occasional episodes of flooding. Thus in February 1971, when severe floods scoured sand and gravel from the river channel, it was noted that this petrologically and granulometrically distinctive sediment was afterwards present on the beach near the river mouth (McLennan 1972). It was soon dispersed by shore processes, and evidently this occasional delivery of fluvial sand has not been sufficient to maintain or prograde the shoreline at the mouth of the Snowy.

On some sectors of the coast, beaches are supplied with sediment eroded from nearby cliffs and rocky shore outcrops. Gill (1978) has demonstrated a relationship between the volume of sand thought to have been generated by Holocene recession of dune calcarenite cliffs east of Yambuk and the volume of sand deposited in Holocene times on Cape Reaumur, a promontory that has trapped sand drifting eastwards. The onset of beach erosion here would presumably be the outcome of a diminishing rate of sediment yield from the eroding cliffs. However, in essaying such





PLATE 6

The prograded grassy sand terrace in the bay at Wingan Inlet, shortly before it was cut away by storm waves. (*N. Rosengren, November 1973*)

correlations it is necessary to take account of losses by solution and attrition, as well as inputs from more distant alongshore and from offshore sources, and the validity of correlation depends on a strict lithological equivalence of the eroded and deposited sand. Along the Otway and South Gippsland coasts, for example, the beaches are of calcareous and quartzose sand while the formations eroding in the cliffs are felspathic; and in East Gippsland the quartzose Holocene beach deposits that extend from Corner Inlet to Cape Howe cannot be correlated with sediment yields from the very limited cliffy sectors. The bulk of the sand forming beaches and coastal dunes in Victoria has evidently been supplied from the sea floor during successive marine transgressions in Quaternary times (Bird 1961), and the onset of erosion should be sought in terms of a diminution in this source of supply.

An explanation may be found in changes in the relative levels of land and sea. Fairbridge (1966) reported evidence from tide gauge records of a worldwide rise of sea level during the past century, at an average rate of just over a millimetre a year. According to Bruun (1962) a shoreline that had previously attained a transverse equilibrium profile would recede in response to such a sea level rise, sand being transferred from the beach to the nearshore sea floor in such way as to restore the transverse profile farther landward (Fig 30 in Bird 1976b). This sequence has been observed on the shores of the Great Lakes in North America during phases of rising lake level, such as the one-metre rise recorded in Lake Erie between 1965 and 1974 (Carter 1976). However it is unlikely that the much smaller rise of sea level, averaging only about a millimetre a year, has had much effect on an ocean shore, where heavy swells and storm waves sometimes exceed 3 metres in amplitude.

It is difficult to determine whether the sea level rise reported by Fairbridge has actually taken place on the coast of Victoria. Indeed, the only long-term tide gauge records available in southeastern Australia are those for Williamstown, at the head of Port Phillip Bay (1858-1939 and 1943 onwards), and Fort Denison, in Sydney Harbour (1867 onwards) (Easton 1970). According to Mackenzie (1939) the levels of mean high and mean low spring tides recorded on the Williamstown tide gauge over three periods 1874-88, 1888-1916 and 1916-35 varied by only  $\pm 0.01$  feet, indicating no significant change in mean sea level within Port Phillip Bay between the eighteen-seventies and the nineteen-thirties, but the validity of long-term sea level deductions from this gauge has been questioned by Bradley (1949). On the other hand, the Fort Denison tide gauge has shown irregular fluctuations of annual sea level over the period 1890-1962, reaching a peak of 3.22 feet in 1919 and troughs of 2.80 feet in

1916 and 1927. The 1962 mean was 3.10 feet, compared with 3.16 in 1890 (Foster 1970). Thus neither station supports the concept of a rise of sea level during the past century, but the Williamstown record could include a response to the blasting of a deeper entrance channel to Port Phillip Bay after 1900, and the Fort Denison record may have been influenced by dredging and reclamation within Sydney Harbour. Unfortunately, there are no stations on the ocean shore that have been in operation long enough to determine sea level trends in the coastal environment.

The effects of tectonic subsidence in coastal regions would be similar to those of a sea level rise, but there is no evidence of such subsidence along the Victorian coast during the past century.

It has been argued that an increase in storminess in coastal waters could lead to the onset of erosion on sandy shores that had been built up under earlier, calmer conditions. Climatic records are too brief to permit a comparison of the incidence and severity of storms during the past century with conditions at earlier times, and so this hypothesis cannot be tested. However, Wilson and Hendy (1971) have argued that an increase in storminess is likely to be correlated with cooling phases of climatic history, when the thermal gradient between the equator and the poles steepens. As such phases are also correlated with falling, rather than rising, sea levels, it appears that the past century should have been an era of diminishing, rather than increasing, storminess.

Even within Victoria, sandy shoreline erosion has been too widespread to be attributable, directly or indirectly, to man's interference, although there have certainly been localised effects following the construction of sea walls and breakwaters. Reduction of backshore dunes following the depletion or removal of vegetation by trampling, burning, and stock grazing has been documented on the Victorian coast (e.g. Rawlinson 1877), and this could have accelerated coastal retreat by diminishing the volume of terrain to be removed as the shoreline is cut back, but it cannot explain *initiation* of sandy shoreline erosion.

Finally, it has been suggested by Tanner and Stapor (1972) that the onset of sandy shoreline erosion, as a sequel to earlier progradation, is an inevitable consequence of an episode of sea level stillstand following the Holocene marine transgression. It is now widely acknowledged that this sea level rise was accompanied by the collection and shoreward drifting of sediments, including sand deposited by rivers draining to lower late Pleistocene sea levels, relics of beach, barrier and dune sands left stranded during the preceding sea level fall, and sandy weathered materials that mantled the submerging land surface (e.g. La Bourdieu 1958, Bird 1961, Russell 1967, Thom 1968, 1974). It